

Entered as second class matter at the New York, N. Y. Post Office, November 26th, 1890.

VOLUME IX. }
NUMBER 2. }

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Annual Subscription \$5.00

Single Copies - 50 cts.

FEBRUARY, 1892.

TRANSACTIONS
OF THE
AMERICAN INSTITUTE
OF
ELECTRICAL ENGINEERS.

REGULAR MEETING, FEBRUARY 16TH, 1892.

A Proposed System of Alternating-Direct Current Transformation.

BY LIEUT. F. JARVIS PATTEN.

Note on the Molecular Movement in a Conductor.

BY PROF. A. E. DOLBEAR.

PUBLISHED MONTHLY BY THE INSTITUTE, UNDER THE
SUPERVISION OF THE EDITING COMMITTEE.

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12 WEST THIRTY-FIRST STREET.
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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, February 16, 1892.

The 64th meeting of the American Institute of Electrical Engineers was held this date, at No. 12 West Thirty-first Street. The meeting was called to order by Vice-President Francis B. Crocker.

THE CHAIRMAN:—We have two papers for this evening's meeting. The subject of the first one, although not at all familiar, is nevertheless very interesting and sooner or later will be a matter of importance. In fact I doubt not that a great many inventors are now working on this very problem, and although it now strikes us as peculiar, this combination of alternating and direct currents, each of which we are used to consider separately, nevertheless it is merely a question of a few months, I think, when systems of this sort will often be the subject of discussion. Without any further delay, therefore, I will announce the paper of the evening on "A Proposed System of Alternating Direct Current Transformation," and introduce Lieutenant F. Jarvis Patten, as the author.

*A paper read at the 66th Meeting of the American
Institute of Electrical Engineers, New York,
February 16th, 1890, Vice-President Crocker
in the Chair.*

A PROPOSED SYSTEM OF ALTERNATING-DIRECT CURRENT TRANSFORMATION.

BY LIEUTENANT F. JARVIS PATTEN.

Recent German practice has given unforeseen importance to all devices for transforming and rectifying alternating currents. The year just passed has been fruitful in the development of multiphase systems, and the new departures are marked by novelty and ingenuity. I have followed these steps with close attention, for they open to the electrical engineer a comparatively new and very interesting field.

The system of transformation which it is the purpose of this paper to lay before you, has arisen mainly from my study of multiphase current developments, and I style it a proposed system, because I have not yet had an opportunity to test it in the completed form and can therefore give no data as to efficiency.

Quoting an author who has written interesting descriptions of multiphased apparatus for the *Electrical Review* of London, after describing the Shuckert motor transformer, which you will remember was brought to your notice by Mr. Carl Hering, in his interesting reminiscences of the Frankfort Exhibition, the author in closing sums up as follows :

"The present importance of these currents (multiphased) may be greatly diminished by the discovery of an apparatus capable of transforming a single alternating current economically into a continuous current. It is also possible and even probable that multiphased currents will constitute merely a transitory system, as the Jablochkoff candle constituted a transitory system between the arc and incandescent lamp."

While it is not my desire to detract in any way from the known merits and beauty of multiphase systems, I have always main-

tained that two wires ought to be sufficient for all purposes, and the system here presented is simply offered as a solution of the problem of obtaining electrical energy in any desired form from a single high tension alternating current.

To merely reverse all the positive or negative impulses of a single alternating current would evidently not be a solution of this problem. The resulting current and the magnetism it produces are pulsating in character, having zero periods at each re-

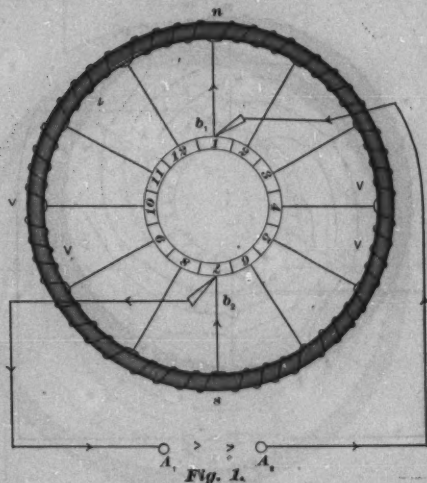


Fig. 1.

versal of current. A useful direct current must be obtained, or one having a practically uniform electromotive force.

To explain the methods used, I must direct your attention briefly to a former paper, read about two years ago, describing an alternating motor which was new at that time, as well as to the Shuckert machine before referred to.

A combination of the functions of these two machines renders possible a number of singular and interesting transformations, which, if they are not entirely novel, any description they may have received has escaped my notice.

The essential features of what for convenience I will style the

"Patten motor," are shown in Figs. 1 to 3 of the drawings, and the Shuckert machine is shown by diagram in Fig. 6.

To explain the former, Fig. 1 is an ordinary Gramme winding and collector, in which a direct current applied to the brushes would make, say, the poles indicated n and s . A source of alternating current connected to the brushes, however, would reverse the polarities of the ring at each reversal of current, and the tendency to motion would of course be reversed if the fields remained

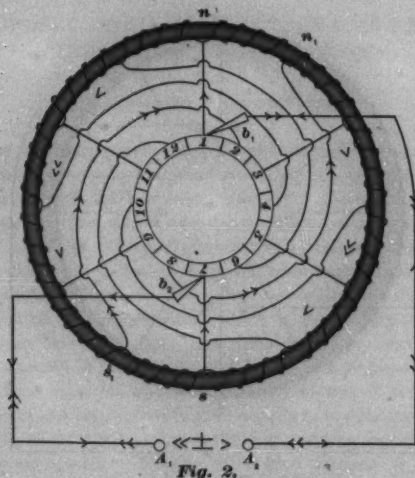
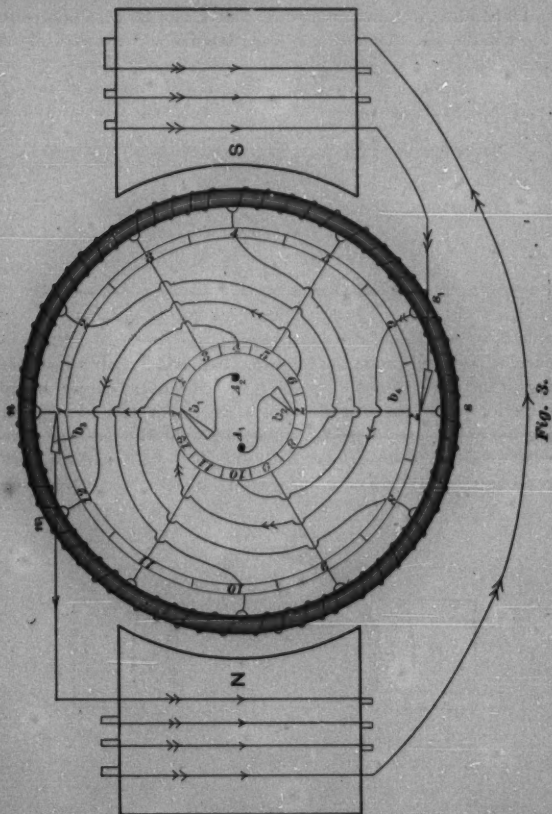


Fig. 2.

the same, but would continue in the same direction if the fields were also reversed by the same alternations of current. If, however, the fields n and s were maintained constant, and by some device the brushes b_1 and b_2 , Fig. 1, could be made to change places at each reversal of current, then with an alternating current the polarities n and s of the ring would remain unchanged, and in a constant field the tendency to motion would still be continuously in the same direction.

It is not practicable to move the brushes mechanically, but the same effect is obtained by the system of armature connections shown in Fig. 2, where the odd numbered bars of the collector are connected to the winding in the usual way, but the interme-

diate even numbered segments are connected to points of the winding diametrically opposite to them.



Such an armature, supplied with an alternating current and placed in a two pole field, will turn through the arc covered by one collector bar at each reversal of current, the polarity of the

ring remaining unchanged, as will be seen by tracing two successive impulses, shown respectively by the single and double arrows.

If, besides the collector just described, another be connected to the winding in the ordinary way, like the outer one in Fig. 3,

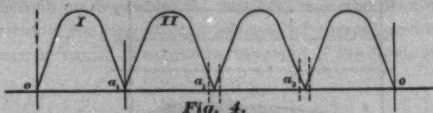


Fig. 4.



Fig. 5.

where, to avoid confusing the drawing, the source of alternating current is shown inside the collector, then evidently brushes bearing on the outer collector will give, as indicated, a current of one direction to any circuit connected to them, as that used for exciting the fields, *n. s.*, Fig. 3. Thus connected, the machine starts itself as would a direct current motor, both fields and armature reversing, but it will continue gaining in speed until one seg-

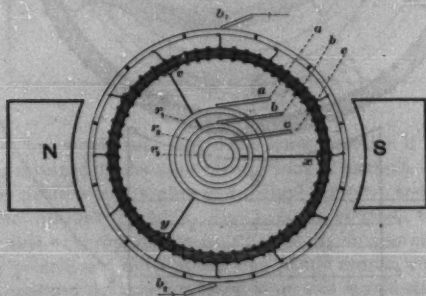
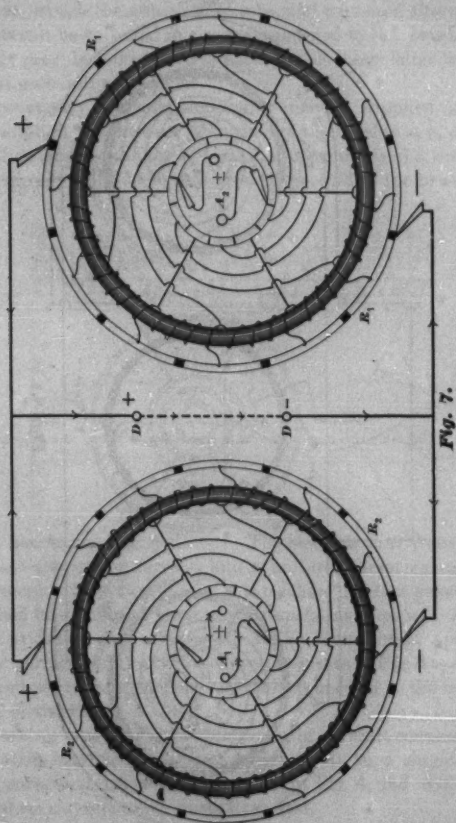


Fig. 6.

ment of the collectors pass their brushes at each reversal of current, when it becomes a synchronous alternating motor, having a fixed and uniform speed—that of commutation. And it may be given almost any speed as compared to that of the generator and

yet be in synchronism, by suitably altering the winding and giving the motor commutator a greater or less number of segments.



Reference will now be made to what will be styled the "Shuckert" machine, a diagram of which is given in Fig. 6, and which will be found extensively described in the London *Electrical Re-*

view of November 20th and December 25th, 1891. It consists of an ordinary Gramme winding and collector, the latter shown for convenience outside the ring. There are also three separate

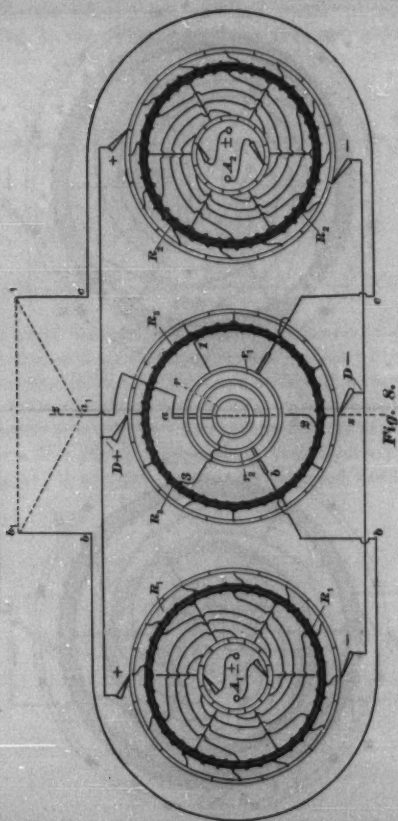


Fig. 8.

ring contacts, r_1 , r_2 , r_3 , provided with brushes a , b , c , and the rings are connected each to one of three equidistant points of the armature winding, x , y , z .

Such a system admits of two important transformations, namely—

A direct current applied at the brushes b_1, b_2 , bearing on the collector, causes the armature to turn, and triphased alternating currents can be collected in circuits connected to the brushes a, b, c . It may be noted here in passing, that these latter will reverse at each half revolution.

Or conversely triphased alternating currents supplied at the rings through the circuits connected to the brushes a, b, c , will cause the armature to turn and (when in synchronism) a uniform direct current will flow in any circuit connected to the brushes b_1

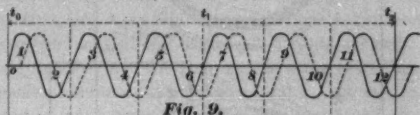


Fig. 9.

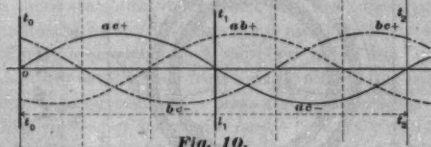


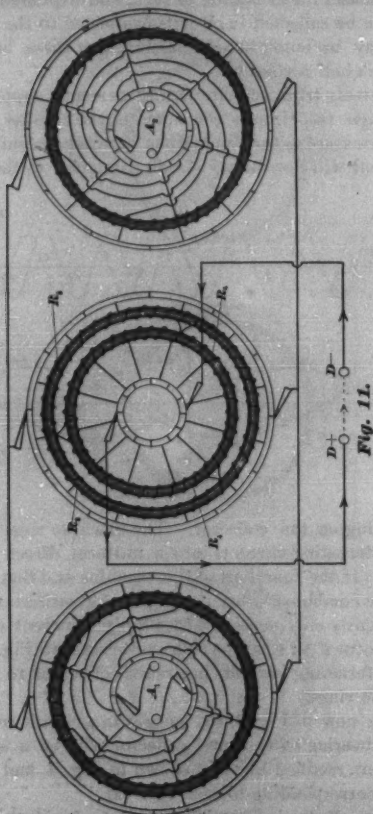
Fig. 10.

and b_2 , bearing on the collector. The machine thus transforms triphased alternating currents into a uniform direct current or the reverse. If the functions of this machine and that previously described be combined, other novel transformations will result, as it is evidently only necessary to supply a current of approximately uniform E. M. F. to the collector brushes in Fig. 6 to obtain triphased alternating currents in circuits connected to the brushes a, b, c , or the rings.

Returning now to Fig. 3, the current in a circuit connected to the brushes bearing on the outer collector will be a single alternating current, rectified like that shown in Fig. 4, and will have zero values corresponding to each reversal.

But if two alternating currents, having a quarter phase difference, be rectified and superposed, a comparatively uniform direct current like that shown in Fig. 5 will result. To obtain this, two armatures like that shown in Fig. 3, secured to a common spindle,

are placed in the same field and are supplied with independent alternating currents differing in phase by a quarter period. This arrangement is shown by diagram in Fig. 7, where the fields are



omitted, alternating currents differing by a quarter period being supplied at A_1 and A_2 , a comparatively uniform direct current like that pictured in Fig. 5, will flow in the circuit $D^+ D^-$. If, now,

these terminals be connected to the brushes of an armature like that shown in Fig. 6, we will have the combination referred to, shown in Fig. 8, in which the middle armature has an ordinary collector shown outside the winding, and three rings with brushes connected to three equidistant points of the winding. The fields are omitted as before and all three windings will be supposed fixed to the same spindle and external circuits, a_1, b_1, c_1 , are connected to the brushes bearing on the rings r_1, r_2, r_3 of the middle armature.

A singular transformation is made possible by this device. Thus single alternating currents differing a quarter phase, supplied at A_1 and A_2 , are transformed in the ring R_3 to triphased alternating currents, but a peculiar feature is here introduced which results from the fact that the triphased currents are only reversed at each half revolution of the ring R_3 , the same as in Fig. 6, while the alternating currents supplied at A_1 and A_2 , as we have seen, are reversed as many times in a single revolution of the rings R_1 and R_2 as there are collector segments, or say, 12 times per revolution, as indicated by the diagrams Fig. 8 and Fig. 3. As the currents differing a quarter period, supplied at A_1 and A_2 , can be obtained on known methods from a single alternating current, we have then here presented *the means of transforming a single alternating current of short wave length or high frequency into triphased alternating currents of long wave length or low frequency.*

Thus a single alternating current like that represented by the unbroken line 1 to 12, in Fig. 9, making 12 reversals in the time t_0 to t_3 , is transformed to triphased alternating currents, making but two reversals in the same time, these latter curves representing as they do the currents in the circuits a_1, b_1, c_1 , Fig. 8, during one revolution of the armature.

The next step consists in changing these triphased currents to a uniform direct current on the plan used in the Shuckert machine, Fig. 6.

Thus, referring to Fig. 11, the winding of the ring R_3 , instead of having three equidistant points connected to rings as before, has them connected to corresponding points of another winding, R_1 , placed on the same core and provided with a separate collector, but to avoid confusion of the drawing the two windings are here shown separately, one inside the other.

Here, as in Fig. 6, a circuit connected to the brushes bearing

on the collector of the ring R_4 will be supplied with a direct current of uniform E. M. F., resulting from the conversion to a direct

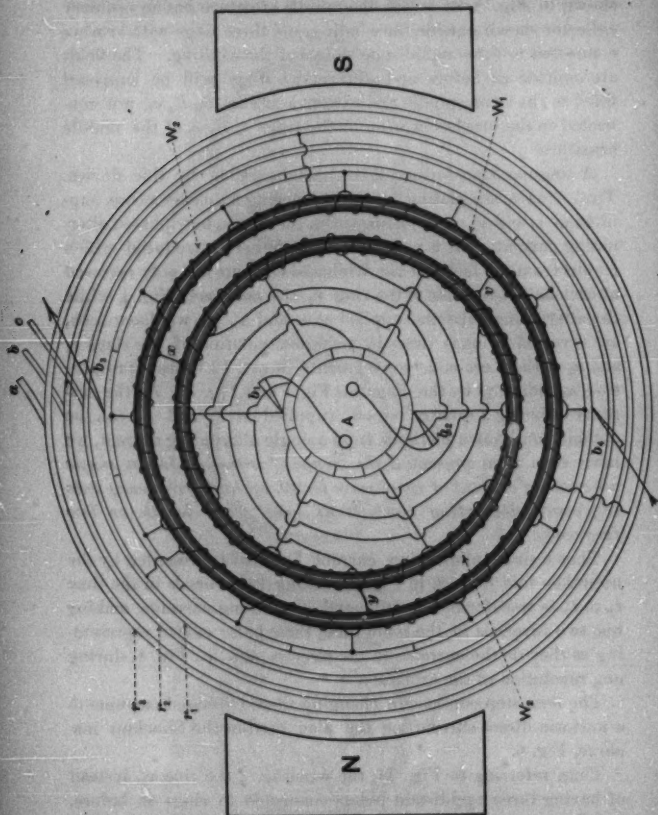


Fig. 12.

current of the triphased currents delivered from the winding R_3 to the winding R_4 .

Here, then, is the means of transforming a single alternating current to a continuous direct current of uniform E. M. F.

Machines like the last two described seem complicated, but approximate if not quite as good results can be obtained from simpler devices. The preceding details were necessary to explain the consecutive steps taken.

As simple a form as that shown in Fig. 12, will probably meet

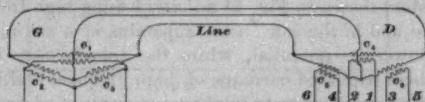


Fig. 13.

the requirements of practice. It represents two independent armature windings carried on the same core, but here shown apart for clearness of illustration. The inner winding, which has a collector directly and reversely connected, as in Fig. 2, is supplied with a single alternating current through the brushes at A. This winding is also connected to the outer one at three equidistant points, as shown, and the outer winding is provided with an ordinary Gramme collector, and if desired, three rings that are connected to three intermediate equidistant points of this winding.

This reduces the machine to a single armature with two windings and two collectors, or at least to two separate armatures and collectors, which form will doubtless be found preferable. The consumption circuit will be connected either to the brushes bearing on the collector or the rings of the secondary winding, according to which function of the machine it is desired to render operative.

Thus a single alternating current of ordinary period may be transformed either to triphased alternating currents of low period or to a direct current of comparatively uniform E. M. F.

If a three wire system, like that shown in Fig. 13, is used throughout, giving triphased currents at the delivery end D, from the secondaries of the three converters, the transformation of these triphased currents to a single direct current of uniform E. M. F., or to triphased currents of a much lower frequency of alternation, can be accomplished on similar lines. It is well known that multiphase motors give better results with currents of comparatively low frequency, 40 to 80 per second being the reported practice abroad.

On the other hand, the converters for reducing potential increase rapidly in size as the frequency of alternation decreases, consequently very large converters are required for such systems. These features are antagonistic and render the conversion apparatus costly if low frequencies are essential to the proper working of rotary field machines.

The system shown in Fig. 14 admits of using high frequencies on the line and in the conversion apparatus at *c* and *d*, for raising and lowering potential, while the transformer, Fig. 14, changes these triphased currents of high frequency either to a uniform direct current or to triphased currents of a lower rate of alternation.

At the delivery end *d*, Fig. 13, separate converters c_1, c_2, c_3 , are used, the secondaries not interlinked having free terminals, as shown, which are taken to the brushes 1, 5, 4 and 2, 3, 6, bearing on the commutator of the ring R_2 , the winding of which is connected at three equidistant points *x*, *v*, *y* of the ordinary Gramme ring and collector R_3 , or to three ring contacts, as may

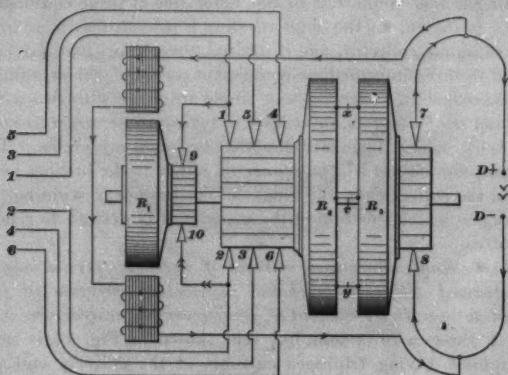


Fig. 14.

be desired, according to whether a direct current or triphased currents is required, as a result of the transformation. The machine R_1 is simply a synchroniser, requiring only sufficient power to drive the apparatus and is supplied with one of the triphased

We have, then, here a means of changing at a single transformation multiphase currents of high frequency to similar multiphase currents of low frequency.

This system admits of using high frequencies on the line, and in the conversion apparatus at both ends of the line, and low frequencies in rotary motors at the delivery end. If, instead of being connected to three rings, the leads x , v , y are connected, as shown in the figure, to another winding, a direct current of uniform E. M. F. will flow in the circuit $D+D-$. This transformer requires no further explanation here.

Fig. 16 shows a developed view of a part of the commutator of the ring R , and the relative positions of the brushes.

To prevent short-circuiting, the segments are separated, as shown, so that a brush will not bear simultaneously on adjacent segments, and for obvious reasons, the brushes have a lag behind each other of two-thirds of a segment. The arrows show how the currents are flowing at the time being. Brush 1 has no current; brush 5 has a positive, and brush 4 a negative impulse.

If these transformations can be made on a large scale economically, it will be possible to supply not only alternating current apparatus of every description, including multiphase devices, but direct current apparatus as well, from a single high tension alternating current. When the original source of supply is a water power, and the distance is not too great the losses of conversion may well be brought within commercial limits.

DISCUSSION.¹

THE CHAIRMAN, [Vice-President Crocker]:—Gentlemen, you have heard this paper which shows great ingenuity, as we should expect from the fact that its author has given us several times before equally ingenious devices. This subject is particularly difficult. You will notice that he has clearly indicated methods of accomplishing four very difficult problems, any one of which would be a sufficient subject for an ordinary paper, I think. In fact some of them would appear to be almost impossible. But I notice one point—he speaks of the fact that low frequency is objectionable in tri-phase transmission, because it requires large converters. That is a fact of course. But I think that the static capacity of the line may be more objectionable than the large transformers, so I would therefore suggest that possibly the line itself may require low frequency. The possibility of transform-

1. By Messrs. Crocker, Carl Herring, Birdsall, Pupin, Louis Bell, Kennelly, Mailloux, Hutchinson, and Hewitt.

ing alternating currents into direct, is certainly novel, and sooner or later bound to be useful. He also suggests how to transform high frequency currents into low frequency currents and *vice versa*. That also is very important, and, will sooner or later probably be a matter of utility in electrical engineering. It is not many years from the time an idea is suggested until it becomes an every day matter and in fact a necessity. This matter is certainly worthy of discussion, and therefore I would suggest that any members who have any comments to make do so.

There is a communication, I believe, from Prof. Dolbear to be considered this evening, in place of the paper of Mr. Sperry. Mr. Sperry is unable to give his paper for various reasons, and Prof. Dolbear has sent an interesting communication in connection with some experiments of his on the molecular effects of currents in wires. Therefore although Lieut. Patten's paper is well worthy of discussion, I would suggest that speakers make their comments as brief as possible.

MR. CARL HERING:—I would like to ask whether such machines have been built and have been run, or whether it is only a proposed system. If they have been run, I would like to ask if there is not considerable sparking at the commutator brushes; it seems to me that at the commutator the current would either be short-circuited, or else the circuit would be opened, either of which would produce sparks.

LIEUT. PATTEN:—I have not put the whole apparatus as described, to a trial, but practically the whole of it, so far as the conversion is concerned, and I think that I see the point that seems difficult to Mr. Hering. The armature soon reaches synchronism, if it is properly constructed, and then the sparking practically disappears. The conversion to a direct current of the form shown in Fig. 4 is I think practically perfect, and I will explain at the board how the short-circuiting is avoided. If the armature is not properly built, and the machine does not acquire synchronism readily, the sparking is bad indeed, no question about that. As to short-circuiting, suppose the brushes instead of being as indicated in the figures, are at a point where they bear on two segments at the same time, [referring to black board] then of course the current coming in could go either way, and would have a short-circuit. To prevent that, a large insulation is placed between segments, broader than the brush contact, so that we practically get a current broken at nearly zero potential, and we have the sparking due to that potential only. When the machine is in synchronism it is very slight. I have only tried it with a machine supplied with about 2,000 watts, and less, but the results were quite satisfactory.

MR. BIRDSALL:—I would like to ask Lieut. Patten if a motor like Fig. 3 has been built?

LIEUT. PATTEN:—Yes sir; many of them.

MR. BIRDSALL:—And the current taken from the outside commutator charged the field magnets?

LIEUT. PATTEN :—Yes, and this rectified current makes to all appearances a perfect field, but really it is not so. It seems to be a constant field, and will hold a heavy piece of iron very nicely ; but it is not a constant field as we know by experiments made by others in a more delicate manner.

MR. BIRDSALL :—But it makes a sufficient field to run the machine?

LIEUT. PATTEN :—Oh yes. I have taken a five h. p. Perret motor and turned it into the form shown in Fig. 3, and while it does not give the power that it would on a direct current of uniform E. M. F., still to all appearances the field magnetism seems to be perfect. Take the armature out and the field magnet seems almost as perfect as with the ordinary direct current.

DR. M. I. PUPIN :—I wish to make a few remarks about a machine that I constructed myself for the purpose of transforming alternating currents, that is alternating polyphasal currents. If we have two armatures—ring armatures, say, and we send a three phase current through the coils of one armature, we create a rotating field. Now, say that between the outside and the inside armature there is a piece of iron which has a smaller magnetic resistance in one direction—serves as it were, to bridge over the lines of force from the outside armature to the inside ; and if this iron bridge, as I may call it, is rigidly attached to a shaft which carries brushes, the result will be that if the inside armature is stationary and the outside armature is stationary and the field rotates, that it will carry this iron piece with it and with the iron piece it will carry the brushes, and therefore if the inside armature is connected to a commutator we shall be able, as soon as the brushes are in synchronism with the rotating field, to take off the direct current from the commutator.

It is understood, of course, that the brush-carrying iron bridge must be provided with a reaction coil which will start it and bring it into synchronism with the rotating field.

The arrangement can also be made to have the outside and inside armature in contact and provide a small three phase motor to carry the brushes and bring them into synchronism with the rotating field. The three phase motor will be capable of getting into synchronism with the rotating field if the reluctance of its armature is very small in one particular direction as compared to its reluctance in any other direction.

LIEUT. PATTEN :—I will explain the difficulty. Among many different forms in which I have tried these experiments, I have explained only a few, thinking that it would make too long a paper anyhow. I have tried the one just explained. It is perfectly feasible, if you can get the speed. But I think I can make it plain where the trouble comes in. If that were a solution, the Shuckert machine would end the whole matter. [Illustrating.] I have indicated here briefly, a Gramme ring. Instead of drawing all the coils, I have indicated the three equal parts of the entire

winding, and *a, b, c* are the terminals of three equal coils or parts of the entire winding. Now, as this armature turns through space, the currents in these different coils will reverse as they pass the neutral line of the field only, consequently we must look for an alternation of current in each coil corresponding to each half revolution. Take an alternating current that has 288 reversals per second. For that machine to get into synchronism, what has to happen? Its armature must turn at such a speed that each coil will pass the neutral line of the field 288 times a second or—you can easily figure it out—something like 8,000 revolutions a minute. Now, there is the whole difficulty with this machine, and if you make multipolar machines you are not much better off, for the reason that, first, the connections become very complex and then we must divide the ring into a number of multiple magnets, and the rotary field effect which causes the armature to turn, loses its power in a great measure. It does not produce the same starting power that you can get out of a device like this, and this constitutes the main difference between the plan suggested by the gentleman who just spoke and the one which I have described.

DR. PUPIN:—These two objections, I think, are very easily overcome. In the first place, the alternation of the polyphasal current which is transmitted to this transformer, should not be too high, and the static capacity should not be too high, because these machines are called upon to transmit energy to a very long distance, and as soon as you transmit energy over a long distance you have to take into account the line capacity, and the line capacity prevents high frequency. The armature may rotate twenty times per second or 1,200 times per minute in the case of a bipolar three phasal machine.

LIEUT. PATTEN:—I admit that with low frequencies there is very little difference between the two.

DR. PUPIN:—Secondly, with regard to the formation of the poles. A three phase machine does not necessarily imply that the ring armature is to have three coils. In fact, it must have six coils. Then the ampere turns are perfectly symmetrical, and therefore the magnetization is perfectly symmetrical.

MR. CARL HERING:—I think one of the points made is not well taken. I understood Lieut. Patten to say that three phase current motors are confined to two pole motors. This is a mistake, as the largest one ever built was the one at Lauffen, which had eight poles.

LIEUT. PATTEN:—I am well aware of that fact, but I understood with low frequencies, and not with high frequencies. I do not know that it would make any difference.

DR. LOUIS BELL:—I am very much interested in this discussion of the possible means of transforming currents in some rather unusual ways. But I would, as a matter of engineering practice, like to know whether there are special advantages to be

gained from using these unusual forms of machines over what would be obtained by using one straightforward direct current, or synchronous alternating, or polyphase machine, and then using two receiving machines coupled together, one of them for the purpose of handling the current as a motor, the other to give out whatever sort of current might be desired. For instance, you might go back to so old and simple a form of machine as the spherical armature T-H arc machines, with which all are perfectly familiar. Machine No. 1 would operate very well as a generator, machine No. 2 as a direct current motor to furnish by machine No. 3 either direct currents or by putting on collecting rings, a drehstrom current, which could be utilized in any form of motor which might seem desirable. In the next place, by putting collecting rings on both generating and receiving machines it would operate fairly well as a drehstrom system, and by using one of the collector rings on the second receiving machine you would be able to get an ordinary alternating current of low frequency. I simply mention that form of machine as a type. The point I want to get at is the advantage to be gained by these unusual though very interesting windings over a straightforward combination of generator at one end of the line and motor generator at the other, consisting perhaps of two machines coupled together in a way that would immediately suggest itself in ordinary engineering. The alternating current lends itself to being played with in a most interesting fashion. You can secure from it almost anything that may seem desirable to use in reference to any particular problem. But as a matter of straightforward engineering practice, I would like to know whether there is a material advantage in efficiency or convenience to be gained from employing unusual forms of machines instead of the ordinary dynamo at one end and the motor and generator at the other.

THE CHAIRMAN [Vice President Crocker]:—I have heard Prof. Thomson himself, I think in this very room, say that his arc dynamo can be used as a motor, but I think it is of rather low efficiency. But I understand Dr. Bell to suggest it merely as a possible apparatus. I myself think that direct current motors can be worked on a direct current line of even as high voltage as 30,000 to 50,000, which is supposed to be only within the range of alternating current apparatus. The only difficulty, of course, is to obtain direct current machines that are capable of working at that high voltage. I do not think it is at all impossible. We now have dynamos that will generate 5,000 volts of direct current. That was true five or six years ago. I think that now, or perhaps a few years hence, we may be able to produce direct current machines of 30,000 to 50,000 volts, which is high enough for transmission over one or more miles of line. As Dr. Bell says, this eliminates many complications, especially the static capacity of the line, which is almost as great a difficulty in long-distance power transmission by alternating currents as it is in

cable telegraphy, and we all know that in that case it is one of the greatest obstacles that has ever been encountered in electrical engineering, and I believe it is almost an equally insurmountable difficulty in very long-distance transmission of power with alternating currents. With the direct current, the static capacity is of no consequence whatever, because it simply charges up the line once or twice per day which amounts to nothing, but if we charge and discharge the line a hundred times, or even thirty and forty times per second with the alternating current, it will require a large part of the current generated by the dynamo. To be sure, this does not consume energy necessarily, but it uses up the capacity of the generating plant, and that is nearly as bad. Having the energy playing in and out of the line, although it may not be consumed, is almost as objectionable as having it consumed, if we get little at the receiving end. If a plan intended to transmit three hundred horse power, transmits but fifty or one hundred, the plant is practically useless.

MR. E. T. BIRDSALL:—I hardly agree with Dr. Bell and yourself, Mr. Chairman, in regard to there being no reason for the use of these multiphase currents, as I have had a little experience in that direction. I had, some time ago, the problem submitted to me of transmitting 5,000 horse power ten miles. I reasoned as the last speaker reasoned—why use alternating currents with the losses in the transformer and the static capacity of the line, and all that sort of thing—why not use one large ordinary continuous current dynamo and a large motor at the other end with a line of shafting, and then put railway generators or anything you please on that shafting? But when I tried to get estimates for direct current dynamos for 5,000 or 10,000 volts pressure from the various companies, they did not appear to be disposed to build them, and much less to make any guarantee as to insulation and whether they would stand, and after a while I found that I must either build this direct current machine myself or else put in an alternating system. That, I think, is the reason why so much attention has recently been given to these multiphase currents and the direct current dynamos have been let alone in this work. Of course, direct current dynamos of high voltage can be figured out on paper. They can be built and they can be run, but the question is, can they be run commercially? If you have to put in a new armature every night, the stockholders are going to be heard from, and everything comes down to that basis after a while. So that, I think, is what has given rise to all the multiphase current work that has been done recently.

DR. BELL:—I want to put myself right before the assembly, on one point. I did not intend to state, nor did I state, I think, that I was a foe of the alternating current, either taken straight or diluted with three phases. I have not anything against it at all. The only point I raised was the relative usefulness of three straightforward machines of any approved type, either synchro-

nous alternating, drehstrom or direct current, as compared with the somewhat complicated, although beautifully ingenious apparatus which has been suggested to-night, for use in general engineering practice. I would not like to put myself on record as believing unreservedly in the use of direct currents at very high tensions. We might find it easier to use the synchronous motor requiring two wires, starting it either by a two-phase motor or some extraneous power, or the drehstrom system, as well as the direct current. The only point is that having a sending dynamo and a receiving motor and dynamo, we can so change the current with which we start as to utilize them most conveniently with practical apparatus that is in everyday use. It is not at all a question of drehstrom against the field, or direct current against continuous. It is simply a question of using three ordinary machines such as we all are familiar with, for transmitting energy, instead of turning to exquisitely ingenious apparatus of at present somewhat uncertain efficiency.

LIEUT. PATTEN:—I wish to answer Dr. Bell on one point. Though apparently complicated, these machines are self-starters, as you will readily see by examining the circuits of Fig. 3, and they do not require multiphase currents or an auxiliary motor to start them, as all other synchronous machines do. If the current is coming, say, in one direction, it makes a certain polarity in the armature, and the shunt circuit makes a corresponding polarity in the field. Of course, when the current reverses, it reverses both field and armature alike, and the machine is thus a self-starter and has that great advantage. It starts the same as a direct current motor would under the same conditions.

MR. A. E. KENNELLY:—This interesting description of ingenious combinations brings us face to face once more with the problem which threatens to be as vital a one in electrical engineering as ever has been the problem of naval defense and offense in quite another sphere. Of course, as has been mentioned to-night, it would be very nice to take an ordinary straightforward direct current dynamo and a similar straightforward direct current motor and couple them together for long-distance transmission, if the cost of the intervening conductor were not a matter of considerable importance, and so, as soon as the length of the line becomes such that the cost of copper is a determining factor, it becomes necessary to raise the pressure. There is now a point where the pressure has to stop, not, as Prof. Crocker has pointed out, that it is essentially obliged to stop, but because it is with the present skill and present knowledge in construction, a matter of necessity for the moment to stop. To overcome the difficulty, therefore, and to enable us to work with high pressures conveniently and safely, the alternating current system has given us the means, for the present time at least, of climbing up to high pressures and climbing down from them with advantage and success. But I look forward to the struggle for supremacy in systems of

long-distance transmission with a certain degree of hope that the difficulties of maintaining and operating high tension, continuous machinery, is a difficulty which will disappear with time, and I see no essential reason why we should not be able, as the Chairman has said to-night, to use in the future, perhaps not in the near future, direct current high pressure machines, without considerable loss in hysteresis, without the large difficulty of overcoming the static capacity of a long line entailing its large amount of dynamo capacity, and with all the direct advantages which a direct system has in its power to bestow. I can only say, then, that while I think we are all interested in whatever tends to overcome this very noble problem of distributing energy within a radius of fifty miles, that the balance of advantage is not wholly, it seems to me, in the direction of alternating current transmission.

THE CHAIRMAN [Vice-President Crocker]:—I would like an opportunity also to explain my meaning to Mr. Birdsall, because I think he misunderstood not only Dr. Bell, but myself also. In the first place, I said nothing that would indicate that the alternating current had no sphere of action whatever, nor did I say that you could buy direct current dynamos of 30,000 or 50,000 volts to-day; nor could you buy any dynamos at all thirty years ago. The fact that makers will not bid on 5,000 or 10,000, still less on 30,000 volt machines, is because they have no demand for them. But I would call Mr. Birdsall's attention to the fact that we have 5,000 volt direct current machines in arc lighting of the ordinary closed coil Gramme-Wood type. As soon as there is a demand for them we will have them. A few years ago, a test with a magneto which failed to show a current through 5,000 ohms was considered high insulation. Now we have 5,000 megohms, and 500,000 megohms for that matter, in some cases. I agree thoroughly with Mr. Kennelly in saying that there is no insurmountable difficulty whatever. It is purely a matter of degree. If we can make 5,000 volt generators, as we can to-day, we can make 10,000 volt generators next month, and 50,000 volt generators in a few years.

MR. BIRDSALL:—I think it only remains for me to agree with the previous speakers to render this discussion harmonious. Of course, I do not pretend to say what will be done in the future any more than I think what was done in the very remote past is of much use to-day. The questions that we have to meet are the problems which come up to-day. That method which promises a solution to-morrow is the one that we work at the most. At the present day, the alternating multiphase current promises more for to-morrow than the direct high pressure current. To-morrow it may be reversed.

MR. C. O. MAILLOUX:—While I admire the beautiful ability of the alternating current to go through the act of "presto, change!" and transmutation, and while I think that it has a

sphere of wide and extended usefulness, yet I am not prepared to believe, as one gentleman said this evening, that it will do everything. It is not as well adapted to cases of transmission and distribution of power on a large scale at constant potential, as it might be. The alternating current has great ability to "get there," but it has not ability to "stay there," or "brace up," because it has not thus far succeeded in solving a very important problem—that of compounding. We can compound a dynamo, so as to make it automatically raise its potential to cover and compensate for any "drop" in the circuit which it feeds. Not so with the transformer, unfortunately. I have a case at present where it is necessary to operate a thousand lights by the alternating current system, though it is impossible to locate the transformers nearer the house than 1,500 or 1,800 feet. The difficulty is complicated by the great distance at which the transformers are situated from the supply station. The loss from the station to the lamps is likely to be anywhere from one to twenty-five per cent., simply because in addition to the large loss on the line (primary), which can not be absolutely compensated for, there will be a large loss in the secondary mains themselves. Now, if it were possible to provide means by which the secondary could compound itself and automatically raise itself as the occasion demanded, when the load increased upon the secondary, I would feel that the transformer was a first class thing for that purpose. But in this case the solution is one far from completely satisfactory. In cases of transformations like those which have been proposed and discussed this evening, this difficulty is emphasized because it is quite evident (and easily demonstrated mathematically) that the greater the loss in the transmission the greater that discrepancy or drop would be between the potential on the primary and the secondary sides of the transforming apparatus, no matter of what kind, if using alternating currents as the primary source. If we have an efficiency of 98 per cent., the "drop" may be quite small, but if our efficiency falls down 40 or 50 per cent., then the inability to "stay there" will be all the more emphasized on the secondary side. That is a point of great importance and which has thus far limited the scope of the alternating current system more than would have otherwise been the case. I understand that many have been at work on this problem, but thus far without very satisfactory results. The best that we can do is to use a higher potential than normally required, and then compound negatively, so to speak, by using so-called "dimmers" or "boosters."

DR. CARY T. HUTCHINSON:—I would like to ask, what are we here for? I thought it was to discuss the Patten motor. But it does not seem to be so at present.

THE CHAIRMAN [Vice-President Crocker]:—I do not know that there is anything in our Constitution or By-laws that limits us to the Patten motor this evening. But still, there is a certain

amount of relevancy in that remark, and the Patten motor is open for discussion. Possibly the Patten motor needs no discussion. It is very well explained by the author. Moreover, it does involve the question of long-distance transmission and distribution. In that connection, I would say that Mr. Birdsall's idea of ten miles for long-distance transmission is rather short, I think.

MR. BIRDSALL:—No, not when you have to figure dividends for the stockholders.

THE CHAIRMAN [Vice-President Crocker]:—The pace has been set by the Frankfort-Lauffen transmission at 50 or 100 miles. Ten miles is for ordinary arc lighting or power circuits.

MR. CHAS. HEWITT:—Dr. Bell has asked what advantages such an arrangement as is under discussion to-night has over the direct current transformation. There is one point which, by the way, is not electrical, that I would suggest, although I may seem heretical for doing so. It is the danger to the operator. When the distance to be covered reaches, say 10 miles, and the power to be transmitted is of sufficient amount, higher potentials have to be used than men are accustomed to handle. If we generate such pressures with direct current dynamos, which must be handled, it becomes exceedingly dangerous. We cannot count on the first honor man of some university to run such a machine, but must rely on men of but moderate intelligence.

These multiphase motors and generators lend themselves beautifully to this practical and serious question. The current can be generated at low pressure, say 100 to 500 volts. All apparatus that must be handled can be placed in the low pressure circuits, while all wires and apparatus carrying the high pressure, dangerous current can be placed entirely out of reach. I think this is a point which we certainly should not lose sight of, and I know that none of us would wish to feel responsible for the life of some poor fellow who had to operate a 50,000 volt direct current generator.

THE CHAIRMAN [Vice-President Crocker]:—I do not personally consider that a 50,000 volt generator is much more dangerous than a 5,000 or even 2,000 volt generator. I think it has been demonstrated that 1,000 volts will kill. If that is the case, I do not see that 50,000 is much worse than 2,000. Either will kill, and it is like a man falling off a house 50 feet high, and falling off one 500 feet high.

MR. BIRDSALL:—Yes, Mr. Chairman, but the house that is 50 feet high has rubber on the roof and the one that is 5,000 feet high has ice on the roof. That is the difference. The 50,000 volt current will leak, break down the insulation and offer many more opportunities for accidents than the one of 5,000 volts.

MR. HEWITT:—The Chairman fails to catch the point I am making. In one case the high pressure can be put absolutely out of reach, in the other it can not. It is comparatively easy to make apparatus for handling and controlling 2,000 volt currents,

but when it comes to controlling 50,000 volt or even 15,000 volt currents by means of switches and other appliances, the difficulties are almost insurmountable.

MR. MAILLOUX :—To come back to the Patten motor, I would like to ask Lieut. Patten whether there would not be considerable difficulty in producing machines capable of developing such high potentials as have been considered here this evening—say 15,000 or 20,000 volts. I speak of this because, owing to the relative complication and multiplicity of circuits in the machines, it appears to me that it would be difficult to produce machines capable of giving that voltage without unduly increasing the number of commutator segments, so as to get the necessary insulation between the point of high and low potential.

LIEUT. PATTEN :—The machines described are intended only for the low tension circuit after the reduction of potential has taken place. The entire system contemplates a closed high tension circuit like that used in the Lauffen-Frankfort tests, where there was no break whatever in the high tension circuit.

The Secretary read the following list of Associate Members elected at Council meeting, Feb. 16th, 1892 :

Name.	Address.	Endorsed by
DELAND, FRED,	Western Manager. The Electrical World 465 The Rookery, Chicago, Ill.	Edw. Caldwell. Louis Bell. Wm. A. Rosenbaum.
GRAY, ELISHA	Highland Park, Ill.	George M. Phelps. Ralph W. Pope. Thos. D. Lockwood.
GRANER, ADOLF	Electrical Patent Agent, 529 North 35th St., Philadelphia, Pa.	Carl Hering. Geo. M. Phelps. Jos. Wetzler.
JAMES, JOHN N.	Electrician, Naval Observatory, Washington, D. C.	Geo. C. Maynard. T. C. Martin. E. G. Willyoung.
McKISSICK, A. F.	Professor of Electrical Engineering, The A. & M. College of Ala., Auburn, Ala.	Ernest Merritt. Harris J. Ryan. Edw. L. Nichols.
SUMMERS, LELAND L.	Assistant Electrician, Western Union Telegraph Co., 18 W. U. Telegraph Bldg., Chicago, Ill.	Edw. Caldwell. W. A. Rosenbaum. Louis Bell.
Total, 6.		

Transfers from Associate to Full Membership; approved by Board of Examiners, Jan. 12th, 1892 :

BURLEIGH, CHARLES B.	Electrician, Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass.
DUNSTON, ROBERT EDWARD.	President, The Connecticut Motor Co., Plantsville, Conn.
HIBBARD, ANGUS S.	General Superintendent, American Telephone and Telegraph Co., 18 Cortlandt St., New York City.
WILSON, CHARLES H.	General Superintendent, Chicago Telephone Co., 203 Washington St., Chicago, Ill.
BENJAMIN, PARK	Electrical Expert and Engineer, 32 Park Place, New York City.

CORRESPONDENCE.

MR. CHAS. PROTEUS STEINMETZ:—When reading Mr. Patten's highly interesting paper on a proposed system of alternating direct current transformation, I noticed again one thing which had occurred to me on a former occasion, namely, that the danger of getting fluctuating currents and fluctuating magnetism by the use of rectified alternating E. M. F.'s is generally highly overestimated. Even in an incandescent lighting circuit, the current caused by a rectified alternating E. M. F. can never approach zero, but as soon as there is any amount of self-induction in the circuit the rectified alternating current and still more the magnetism produced thereby, is practically constant.

How far self-induction and hysteresis suppress fluctuations, I had occasion to observe a short time ago on a pulsating E. M. F., which varied not only between 0 and maximum, but which *reversed*.

A pulsating E. M. F. of 15.8 volts effective, which varied between +26.5 volts and -14.5 volts (so that the negative maximum was somewhat more than one-half the positive maximum), was acting upon a magnetic circuit of 4.5 cm.² cross-section and 41 cm. length, thoroughly laminated against eddies, and surrounded by 100 convolutions of wire.

The frequency was 170. Then the current amounted to 14.5 amperes¹ effective, and fluctuated between +24.8 amperes and -6.0 amperes, that is, was still reversing, but its negative maximum being less than one-fourth the positive maximum.

The magnetism produced by this current fluctuated between +15,500 and +7,400 lines of magnetic force. That is, even a pulsating E. M. F., which reverses in direction to as high a degree as this is not able to reverse magnetism. A non-reversing E. M. F., then, will hardly cause perceptible fluctuations of magnetism. Hence rectified alternating currents are much steadier than generally assumed. But in the alternating part of the line, the current must pass through zero. In the rectified part it never does. Hence, at the synchronizing commutator, there must be a discontinuity, causing a tremendous sparking, if no special precautions are taken against it. This can be done by a short-circuiting arrangement at the brushes, as explained on another occasion.

The method of transforming proposed by Lient. Patteu, is entirely different from this synchronizing device. I do not think it even necessary to use two armature windings. As the simplest form of such a transforming instrumentality I should consider an armature winding, connected to such a cross-connected commutator as Lient. Patten proposes for receiving

1. It is interesting to note that while 15.8 volts effective pulsating E. M. F. sent 14.5 amperes through the circuit, 15.8 volts effective alternating E. M. F. sent a current of only 1.6 amperes through the same circuit with the same frequency.

high-frequency alternating currents, and at the same time connected to an ordinary continuous current commutator, to receive or to deliver continuous currents, while this commutator is tapped at several points and connected to sliding rings, wherefrom low frequency alternating or polyphase currents can be taken off or sent in.

If, then, for instance, a high frequency alternating current enters the Patten commutator, it sets the machine in motion as an alternating motor, while the same machine as a continuous current dynamo delivers a steady continuous current at the other commutator. But this continuous current is not to be considered as the rectified alternating current, and therefore is not pulsating, but is the steady current of a continuous current dynamo, a dynamo, indeed, which is not set in motion by a belt, but by using the same machine as an alternating motor.

I have used such a machine a long time, especially for transforming continuous currents into low frequency alternating or

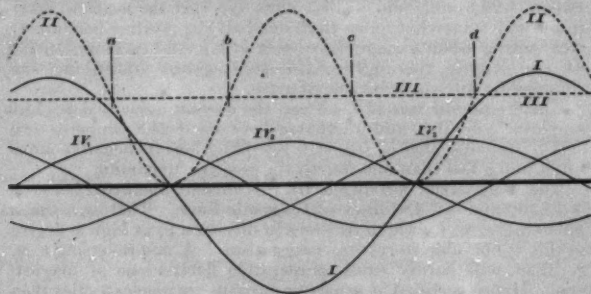


FIG. 17.

pulsating currents, as explained in my paper on hysteresis. Several times I connected the alternating brushes of this machine with the alternating brushes of another such machine, and so derived a power transmission, where the current in both stations is continuous, while the live current is alternating. Let us consider the general principle of such a conversion of alternating into continuous currents, etc.

In Fig. 17, curve *I* represents an alternating current, curve *II* the power or the effect of this current, straight line *III* the power of a continuous current of equal power. As seen, the instantaneous power values of the alternating current fluctuate between zero and maximum, are larger than those of the continuous current from *b* to *c*, smaller from *a* to *b*, *c* to *d*. Hence to convert the alternating current *I*, *II* into the steady current *III*, an instrumentality is necessary which is able to take up during the time *b* — *c*

the surplus amount of alternating current energy, to store this up and deliver it back to the circuit during the time $c - d$. Therefore a simple synchronizing device is not sufficient to straighten alternating currents.

In Patten's proposition this electric energy is stored up as mechanical momentum. During $b - c$ the transformer accelerates, during $c - d$ its speed slows down. But the consequence thereof is that the transformer has to be of sufficient size to give this momentum.

By the use of self-induction for straightening the commutated alternating current, this surplus energy is stored as magnetic potential, by the use of condensers as electrostatic charge; by the use of storage battery as chemical affinity—all these ways can be made to answer the purpose of straightening a commutated alternating current so as to make it practically steady or constant.

I wish to direct attention to one remarkable fact with regard to the polyphasal system. If we have, for instance, three polyphasal currents, iv_1 , iv_2 , iv_3 , and add their power curves together we get the *straight line* III. That means,

"While in an alternating current system the instantaneous power values fluctuate twice during each period between zero and a maximum, in a polyphasal system the instantaneous power values of the system remain constant just as in a continuous current system."

The consequence thereof is that in transforming from polyphasal to continuous currents and back, there is neither storing up of energy nor armature reaction present, and therefore the transformer can be made as small and with as much wire on the armature as wanted, while when transforming between alternating and polyphasal or continuous current, energy has to be stored up, armature reactions will take place, etc., and the transformer must have a certain size to answer the purpose.

Feb. 21st, 1892.

PROF. ELIHU THOMSON:—The proposed system of Lieut. Patten is based on the *commutation* of alternating currents. This appears to be the fundamental idea, out of which he develops his various figures and methods. These are very pretty in theory, but not very practicable, in my opinion. To commute an alternating current of any considerable potential is not practicable by any means such as Lieut. Patten shows. There would need to be an absolute fixedness of phase, and a theoretically perfect commutation. Neither of these are attainable in practice. Short circuits and burning at the commutators would be inevitable, except in small models. Even if the potential of the currents to be commutated is made very low, the difficulties of commutation do not disappear, and much larger commutators would be needed. When Lieut. Patten succeeds, *practically*, in commutating alternating currents representing, say, 10 to 20 h. p., by the plan

shown in Figs. 1 and 2, the consideration of his other plans or figures based thereon, would seem to be in order. The difficulty is that electrical currents will not always do what has been marked out for them on paper, and Lieut. Patten falls into the error of presenting as solutions of various problems and even emphasizing them in italics, merely diagrams on paper, which might represent actual conditions if the currents dealt with had only a small potential and at the same time small strength. In practice, the facts of self-induction and distortions, and the fact that a commutator of alternate positive and negative segments with brushes which *ought to be* exactly on the *line* between the segments when the current is zero is not a very easy thing to work, and keep in order, are rather against such systems as are proposed in the paper before us.

Feb. 29, 1892.

Read at the sixty-fourth meeting of the American Institute of Electrical Engineers, New York, February 10th, 1892, Vice-President Crocker in the Chair.

NOTE ON THE MOLECULAR MOVEMENT IN A CONDUCTOR.

BY PROF. A. E. DOLBEAR.

Maxwell and others have made experiments to discover whether there was any evidence of momentum in a conductor carrying an electric current. So far as I know all the experimenters looked for a *longitudinal* momentum, that is, one in the direction of the current in the conductor, but no evidence appears to have been discovered that the molecules are thus moved. Still it is as near certain as anything can be and not be demonstrated, that the molecules in a conductor are moved in some way by an electric current. If they be thus moved then there must be momentum in some direction. If it be not longitudinal it may be transverse. If there should be movement in the transverse direction, what kind of experiments would be needed to show it? This is the way the question presented itself to me. When a current is sent through an *iron* wire the latter is twisted, to the right or the left according to the direction of the current. This is interpreted as due to the specific magnetic quality of the conductor, for it does not occur in a copper or other conductor.

Suppose the molecules of a conductor to be *rotated*, each upon its own axis, the axis being longitudinal with the wire, what evidence of such motion would be externally exhibited by the conductor as a whole. Evidently it would be masked altogether in a common wire, for the momentum of any one molecule in one direction would be just balanced by that of the contiguous one in the opposite direction—a condition of things mechanically propagated through the diameter of the wire. In order to discover it, it would be necessary to prevent such mechanical transference of the movement, and this can be done by making the conductor a

hollow cylinder. I therefore made a cylinder of gilt paper about 20 inches long and four inches in diameter, this I provided at each end with a bail for suspension, thus: The suspending wire being eight or ten feet long, the lower end of a short wire dipping into a mercury cup as shown. [Fig. 1] With this arrangement a decided evidence of twist could be noticed, but on account of the resistance of the gilt paper, a strong current could not be used without so high a voltage, that the paper took fire several times. I then had a thin copper cylinder made of nearly the same dimensions and suspended in a similar manner, and could use a current of thirty or forty amperes. The rotary motions were in the same directions as before, namely—when the current was going down, the twist was always right handed as indicated by

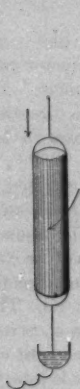


FIG. 1.

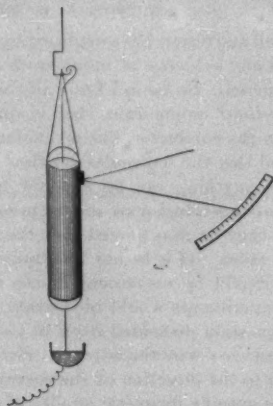


FIG. 2.

the arrow, and of course opposite when the current was reversed. While there was no doubt about the rotary movement, the weight of the apparatus was so great, I concluded to see if one made of lighter material—aluminium, would not give greater amplitude with same current. A similar cylinder of aluminium foil was prepared and so hung that all tangential movement would be due solely to itself and not at all to any other part of the apparatus, that is, it was mounted with bi-filar suspension. The weight of the foil with its connections was 1.85 oz. 55.6 grams. A bit of mirror was fastened to the upper end, and a beam of sunlight

reflected from it upon a scale 16 feet distant, and 25 feet long. [See Fig. 2.] With this arrangement, the twist produced by the current was such that it was not difficult by timing the swings and changing the direction of the current, to make the cylinder swing through 90° . A current of fifteen amperes swung it through a foot and a half of the scale. It would come to rest at about half the distance of the greatest amplitude of the swing, for each different current employed, and *therefore showed the continuous action of the torsional force for a constant current*. If this be the interpretation of the phenomenon, then the molecules are rotating when there is a constant current, and thus the explanation of the heating effect of the current, is brought back to dynamical and mechanical principles. Adjacent molecules must be rotating in opposite directions at their point of contact, but this vibrating or heat motion, necessitates more or less separation, when such rotation goes on; on impact it is arrested so there must be impact and slip, impact and slip. The arrest of motion being the immediate antecedent of the heat, as is friction in any case. These experiments have not been carried out quantitatively for lack of facilities. May be the interpretation is wrong, and some wise one who knows all about it, can point out its inadequacy. I think the experiments are new, and may lead to an understanding of what goes on in a conductor when a current of electricity traverses it, if this be not the whole of it.

DISCUSSION¹.

MR. MAILLOUX:—I do not want to have it thought that I am that wise one, who knows all about it. Yet, while the paper was being read I could not help surmise that the horizontal component of the earth's magnetism may have had a great deal to do with the rotation. It does not seem to me that the experiment is conclusive until it shall have been tried in different relations with respect to the earth's magnetism, and the effect of different magnetic fields in its neighborhood has been tested. Since the current travels in a vertical direction and the lines of force form circles concentric with its line of motion, it is quite evident that any magnetic field, however feeble, must have some effect upon the conductor. The difference of magnetic potential on two sides of that tube has a different relation to the magnetomotive force of the earth's magnetic circuit. One side would tend to add such portions or elements of its force as are of the same magnetic polarity or direction, while those on the other side being of

1. By Messrs. Mailloux, Wolcott, Kennelly, Pupin, Blinney, Crocker, Sheldon and Kintner.

contrary direction would interpose a contrary magnetomotive force. The effect of that might be to tend to rotate the wire slightly, as well as to translate it laterally.

MR. TOWNSEND WOLCOTT:—Mr. Mailloux's remarks, I think, would hardly apply to continuous rotation. If that tube is perfectly straight and perfectly uniform in resistance, there is no reason for a continuous rotation, but if that tube is crooked it might revolve partially. The reason I take this view of it is that somewhat more than a year ago I saw an experiment tried which was supposed to upset one of Maxwell's experiments, that is, a current going through a straight vertical wire, and when I examined the apparatus I found the wire was not straight. In the experiment of Maxwell it was proved that there is no tendency to rotate magnets—if you place two or more magnets with the similar poles towards the vertical wire and pass a current through it, there is no rotation, that is, on the assumption that the wire is straight. The gentleman who tried the experiment, in order to show that there was some rotation kept commutating the current, just as Prof. Dolbear mentioned. In that way he succeeded in amplifying the swing, so that it showed a very considerable amount. It seems there was not a complete revolution in this experiment. With the very long suspension mentioned in the paper, it seems to me you ought to get at least one revolution if the torque was of any account whatever.

MR. KENNELLY:—Without pretending to make any remarks as to whether this action observed was really due to the cause that Prof. Dolbear has suggested, I merely desire to point out that if that particular cylinder did turn, it is reasonable to suppose that another cylinder inside, concentric with it, would also independently turn, a third one within that would also turn, and so on. Now, if they would each and all separately turn, surely when they were united in one solid mass the whole mass would revolve and I think it is very strange that if such an action would take place, a solid rod of copper pivoted upon its axis should not have been observed to rotate when a current passes through it independent of all magnetic forces.

DR. PUPIN:—I would like to call attention to an experiment made some years ago by Prof. Braun, of the University of Tübingen (Braun, F., *Deformationsströme*, Wiedemann's *Annalen*, vol. 37, p. 97, 107; vol. 38, p. 53; vol. 39, p. 130). He found that a wire made of a magnetizable substance, when twisted one way will generate an electromotive force acting in one direction, and if twisted the opposite way it will produce an *E. M. F.* acting in the opposite direction. Prof. Rowland called my attention to a current interrupter constructed on that principle, where a twisted wire is made to untwist by sending a current through it. Perhaps the phenomenon observed in Prof. Dolbear's interesting experiment may be due to a similar cause.

MR. HAROLD BINNEY:—I think there is a third point not brought out, and that is the effect of the bails. It seems his (Prof. Dolbear's)

experiments were not conclusive, as he used currents first in one direction and then in the other. It is clear that the current in passing downwards would go more in one bail than in another, owing to its tendency to lateral shifting in the magnetic field. In that case, in starting to go downward, it would, let us say, go more in the right hand bail, and if that bail were not exactly perpendicular to the lines of force it would tend to shift it across the field of force and so cause rotation. Then when the current was turned in the opposite direction, if properly timed to the period of the apparatus, the twist would be in the *same direction* as the swing, although it would flow through the other bail, and these infinitesimal impulses properly timed might well cause appreciable rotary oscillations. This may have something to do with the phenomenon observed and is not based on the supposition that there was lack of symmetry in the apparatus. See Fig. 3.

THE CHAIRMAN [Vice-President Crocker]:—I should expect a lack of symmetry there, as Mr. Wolcott suggests. If one side

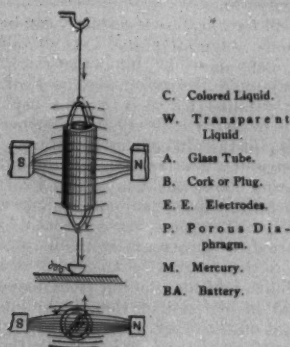


FIG. 3.

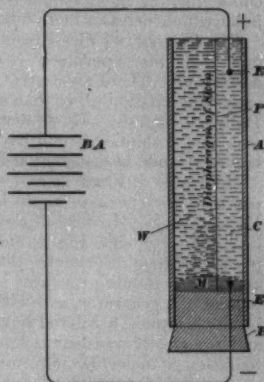


FIG. 4.

was a little thicker than the other, the current would be stronger on that side. That would throw it out of balance and cause rotation, but if it were perfectly symmetrical, according to our present knowledge of electric currents, there would be no tendency to rotate.

MR. MAILLOUX:—I think it would be well to call attention to the fact that a wire or a cylinder situated as that is in the earth's magnetism, would have present in it Hall's phenomenon, that is to say, the current would not be distributed equally throughout the mass of that cylinder. It would be unequally distributed by

the very fact that it was placed in the magnetic field not symmetrically related to the flow of current. That effect, though it might be slight, would further complicate the case and might be in itself a partial explanation of the peculiar actions observed.

MR. WOLCOTT:—I think the whole effect is entirely too small to be noticed there. It will be remembered that Mr. Hall looked for the effect some time before he found it himself, with the very best apparatus.

DR. SAMUEL SHELDON:—Prof. Hall used, I think, between forty and fifty amperes, passing through an ordinary university pattern of the Ruhmkorff magnet, and then used a Thomson reflecting galvanometer of the ordinary pattern and even then obtained a very small deflection.

MR. CARL HERING:—Some interesting results might be obtained if that conducting cylinder were surrounded by a fixed iron cylinder. This would shield it from the earth's field, and if the motion was due to the magnetic lines circulating around that conductor, the effect should be increased, because of the iron cylinder which increases these magnetic lines.

THE CHAIRMAN [Vice-President Crocker]:—It certainly can be said that this experiment is only suggestive and not at all conclusive. There are a great many possible things that might cause this rotation other than any molecular action, such as Prof. Dolbear suggests. He evidently thinks that it is open to suspicion, and I think it would have to be carried very much farther before it could be accepted as one of the phenomena of nature.

MR. CHAS. J. KINTNER:—I suggest a modified form of the apparatus which perhaps might bring about the results that Prof. Dolbear seeks. Instead of a metallic cylinder, suppose we take a light glass cylinder, Fig. 4, and attach in some way a porous diaphragm through the centre thereof, with mercury at the bottom and a wire running upwards into the mercury, connected at one pole of the generator, and with a conductor running from above into two liquids, a colored liquid on one side of the diaphragm and a perfectly transparent liquid on the other. If there be any tendency to molecular movement there, I think it is possible the colored liquid would be forced to rotate through the diaphragm and mix with the transparent liquid.

[Adjourned.]

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SPECIAL NOTICE.

The Annual Meeting for the election of officers, the reception of yearly reports, and the transaction of business, will be held at the headquarters of the Institute in New York City, on Tuesday, May 17th, and will be followed by a dinner in the evening. The General Meeting for the reading and discussion of papers will be held at Chicago, on Monday and Tuesday, June 6th and 7th. The programme of papers is now in preparation.

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